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A LEAST SQUARES INTERPOLATION SCHEME FOR CRYOGENIC THERMOMETERS--ETC(U)
SEP 79 C G GARDNER , E M FYFFE , J J HUDAK
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# A LEAST SQUARES INTERPOLATION SCHEME FOR CRYOGENIC THERMOMETERS USING A HAND-HELD PROGRAMMABLE CALCULATOR

See 1473 on back page

CARL G. GARDNER
ELLEN M. FYFFE
JOHN J. HUDAK

DEPARTMENT OF DEFENSE
9800 Savage Road
Ft. Meade, MD 20755

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## INTRODUCTION

The following is a description of a program for a hand-held programmable calculator which, in effect, interpolates values of temperature from the calibration table of a silicon diode thermometer over a full 4 to 300K temperature range. When making temperature measurements in the laboratory, the voltage across a forward biased calibrated diode is read from a digital voltmeter. With this program, the voltage reading is keyed into the calculator and the interpolated temperature is calculated quickly and accurately. The computational technique presented here is superior to techniques generally used since the data reduction scheme allows more information to be stored, allows for a simple calculator routine resulting in very short computation times and results in an interpolation having the accuracy of the original data table. The scheme is perfectly general and can be used to interpolate any data table.

## GENERAL SCHEME

A common recurring problem in laboratory work is the necessity of interpolation from a table of values. An example is interpolation from a calibration table furnished with a cryogenic silicon diode thermometer where pairs of temperature and voltage values are given.[1] During an experiment, the diode voltage is read from a digital voltmeter, then the corresponding temperature value must be interpolated from the calibration table. It would be very convenient to be able to make this interpolation quickly and with a high degree of accuracy while the experiment is in progress. A hand-held programmable calculator, in our case a Texas Instruments TI-59, can be used to accomplish this.

Before this is done, a number of problems must be overcome. The calibration table supplied with a diode typically may have 90 or more pairs of temperature and voltage values. This would exceed the maximum available memory capacity of the calculator which is about 100 locations. Interpolation can be accomplished by the evaluation of a least square fit polynomial, however the calculator is too slow to do other than the simplest fitting routines in a short period of time. An attempt to fit a polynomial equation to the entire 4 to 300K calibration using a large computer did not result in the desired accuracy. The following procedure was subsequently devised.

The values from the calibration table were divided into overlapping temperature intervals. Then for each interval, a least square polynomial fit was made using a Forsythe fitting method[2] programmed on an IBM 370 computer. Any least square polynomial fit with sufficient accuracy is adequate. The least square polynomial fit program gives an rms error for each polynomial. The temperature intervals were adjusted by trial and error in order to obtain a satisfactory rms error over the full 4 to 300K span. In the case considered here, it was found that 12 polynomials each of 4th order were needed and that the length of the temperature intervals varied over the calibration range. All intervals have a one point overlap with the adjoining intervals. Using the coefficients found to 16 place precision by the IBM 370 computer, the rms error, $\sigma_{370}$, of each polynomial fit is given in Table I. The accuracy obtained preserves the accuracy of the calibration table. The full calibration table was thus reduced to 12 sets of polynomial coefficients, $a_0$, $a_1$, $a_2$, $a_3$, $a_4$, which could all be stored in the calculator. A relatively simple program could then be used to calculate any temperature, T, between 4 and 300K by evaluating

$T = a_4 V^4 + a_3 V^3 + a_2 V^2 + a_1 V + a_0$, where V is the voltage reading across the silicon diode thermometer. Both the coefficients and the calculator program are stored on magnetic cards and a set of magnetic cards can be used to store the coefficients for several different calibrated temperature sensors.

Table I. The temperature intervals and the corresponding rms errors of the 4th order polynomial fit using coefficients having 16 digit precision on an IBM 370, $\sigma_{370}$, and coefficients having 10 digit precision on a TI-59, $\sigma_{59}$.

| Polynomial # | Temp. Interval (K) | $\sigma_{370}$ (K°) | $\sigma_{59}$ (K°) |
|---|---|---|---|
| 1 | 4 - 6.5 | $1 \times 10^{-3}$ | $1 \times 10^{-3}$ |
| 2 | 6.5 - 9.5 | $2 \times 10^{-3}$ | $2 \times 10^{-3}$ |
| 3 | 9.5 - 13 | $9 \times 10^{-12}$ | $3 \times 10^{-5}$ |
| 4 | 13 - 17 | $6 \times 10^{-12}$ | $1 \times 10^{-5}$ |
| 5 | 17 - 21 | $4 \times 10^{-12}$ | $2 \times 10^{-6}$ |
| 6 | 21 - 25 | $6 \times 10^{-12}$ | $1 \times 10^{-4}$ |
| 7 | 25 - 32 | $7 \times 10^{-3}$ | $7 \times 10^{-3}$ |
| 8 | 32 - 55 | $1 \times 10^{-2}$ | $1 \times 10^{-2}$ |
| 9 | 55 - 85 | $1 \times 10^{-2}$ | $1 \times 10^{-2}$ |
| 10 | 85 - 155 | $8 \times 10^{-3}$ | $9 \times 10^{-3}$ |
| 11 | 155 - 245 | $9 \times 10^{-3}$ | $1 \times 10^{-2}$ |
| 12 | 245 - 300 | $2 \times 10^{-3}$ | $2 \times 10^{-3}$ |

## CALCULATOR PROGRAM

The 12 polynomials used each have five coefficients therefore, 60 memory locations are needed for coefficient storage. The program itself uses 13 memory locations for the voltages which define the temperature intervals, 4 locations for accumulation registers and one location for the input voltage. The program itself requires 106 program steps. There are 13 memory locations and 133 program steps not used. The number of memory locations and program steps can be reallocated so that a maximum of fifteen 4th order polynomials can be used if necessary.

The program action is as follows:

a) The voltage drop across the silicon diode is keyed in.

b) The program finds the corresponding voltage interval.

c) The polynomial coefficients corresponding to this interval are located.

d) The fourth order polynomial is evaluated using these coefficients and the resulting interpolated temperature is displayed rounded to three decimal places.

e) If a voltage is entered which lies outside of the range of the calibration the display will flash with the value of the voltage which defines that calibration limit.

Using the TI-59 with the coefficients stored to the 10 digit precision of the calculator, the temperatures were calculated at the known voltage calibration points and checked against the given temperatures from the calibration table. This rms error, $\sigma_{59}$ is given in Table I for comparison. The calculation still preserves the accuracy of the calibration table.

The time required for the calculator to compute the temperature is ten seconds or less. Thus it is possible to take voltage readings and calculate

the temperature while an experiment is in progress. A copy of the TI program is given in the Appendix as Program I. Familiarity with programming language and procedures on the TI-59 are assumed.

EXAMPLE

First, the program must be entered into the calculator. The intial step is to partition the calculator's memory. This is accomplished by keying in 9 2nd OP 17. The calculator responds by displaying 239.89 indicating the correct partition. The display is cleared to 0 and the four sides of the two cards are read into the calculator (The display must be cleared to zero before each card is entered). The calculator is now ready.

Assume a voltage reading of 2.0153 volts. This value is keyed into the calculator and the program is run by pressing "A". The calculator then displays the corresponding temperature 9.758 rounded to 3 decimal places. The accuracy of the result depends on the accuracy of the original calibration and the accuracy of the polynomial fit as discussed above. Table II in the Appendix shows the values stored in the memory locations after this example was run. Memory location 00 stores the input voltage reading. Locations 1-13 contain the voltages which define the temperature intervals starting with the lowest temperature interval first. Location 14 accumulates a value which determines which set of coefficients shall be used. Location 20 through 79 contains the ceofficients of the polynomials starting with the lowest temperature interval first and stored in the order; $a_0$, $a_1$, $a_2$, $a_3$, $a_4$. Location 82 is a counter which equals the memory location of each coefficient to be used. Location 83 stores the result of the evaluated polynomial and location 84 contains this result rounded to three decimal places which is the value to be displayed.

## ANOTHER PROGRAM

The storage capacity limits one to using a maximum of fifteen 4th order polynomials. The data set may be such that the desired accuracy cannot be obtained without exceeding the storage capacity of the calculator. This problem occurred with one of our thermometers and the solution used is presented here.

It was found that in three temperature intervals the fourth order polynomial did not give the desired accuracy. So a fifth order polynomial was calculated for these cases. A program was written for the calculator that selects the appropriate number of coefficients and makes the decision whether to use the 4th or 5th order equation. After selection, the polynomial is evaluated and the temperature displayed. The program, the contents of the memory locations and a flow chart are given in the Appendix under Program II.

It should be noted that this procedure (changing some polynomials to 5th order) was an original attack on the problem. Our present philosophy of attack would be to adjust the range of the polynomials by trial and error with the least square fit program on the IBM 370 to give fits to accepted limits using polynomials all of the same order. Only if this procedure fails should a mixture of orders be used.

## SUMMARY

A method has been found to interpolate values from a large table of data using a hand-held programmable calculator. The method uses a series of overlapping least squared polynomial fits, calculated by a large computer, to reduce the information contained in the table to a small set of polynomial

coefficients. The entire set of coefficients can be stored in the calculator. Interpolation is accomplished quickly and accurately by the programmed evaluation of the polynomial. The method is perfectly general and, in particular, is ideally suited to the interpolation of calibration tables in the laboratory while an experiment is in progress.

REFERENCES


1. Also, the raw calibration data is often available from the supplier upon request if a temperature calibration table is ordered.

2. Louis G. Kelly, "Handbook of Numerical Methods and Applications", Addison-Wesley Publishing Co. 1967, pg. 68.

# APPENDIX

Program I

TITLE Silicon Diode Thermometer #9343 PAGE 1 OF 2

PROGRAMMER Carl G. Gardner DATE 23 April 79

TI Programmable **Program Record**

Partitioning (Op 17) [2,3,9,8,9] Library Module _____ Printer _____ Cards _____

## PROGRAM DESCRIPTION

This silicon diode thermometer interpolation program is designed to calculate the temperature (in deg. Kelvin) corresponding to a given voltage. The calculator performs a search routine to find the correct coefficients, then calculates T using the predetermined coefficients of a least square polynomial fit.

$$T = a_4 V^4 + a_3 V^3 + a_2 V^2 + a_1 V^1 + a_0$$

Range of validity 4.0 to 300K.

## USER INSTRUCTIONS

| STEP | PROCEDURE | ENTER | PRESS | | | DISPLAY |
|---|---|---|---|---|---|---|
| 1 | Partitioning | 9 | 2nd | OP | 17 | 239.89 |
| 2 | Enter program and coefficients from cards Enter sides 1, 2, 3, and 4 (not necessary to be in that order) clear display to 0 before each entry. | | CLR | | | 0 |
| 3 | Enter Voltage (V) | V | | | | V |
| 4 | Calculate Temperature (T) *If a voltage is entered which lies outside of the range of the calibration, the display will flash with the value of the voltage which defines the calibration limit. | | A | | | T* |

| USER DEFINED KEYS | DATA REGISTERS ( STO RCL ) | | LABELS (Op 08) |
|---|---|---|---|
| A | 0 | 0 | |
| B | 1 | 1 | |
| C | 2 | 2 | |
| D | 3 | 3 | |
| E | 4 | 4 | |
| A' | 5 | 5 | |
| B' | 6 | 6 | |
| C' | 7 | 7 | |
| D' | 8 | 8 | |
| E' | 9 | 9 | |

| FLAGS | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|

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Program I

TITLE Silicon Diode Thermometer #9343 PAGE 2 OF 2

PROGRAMMER Carl G. Gardner DATE 23 April 79

TI Programmable **Coding Form**

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| 000 | 76 | LBL | |
| 001 | 11 | A | |
| 002 | 42 | STO | STORE V |
| 003 | 00 | 00 | |
| 004 | 32 | X:T | LOAD T |
| 005 | 43 | RCL | CHECK |
| 006 | 01 | 01 | LOWER |
| 007 | 22 | INV | LIMIT |
| 008 | 77 | GE | |
| 009 | 12 | B | |
| 010 | 43 | RCL | CHECK |
| 011 | 13 | 13 | UPPER |
| 012 | 77 | GE | LIMIT |
| 013 | 12 | B | |
| 014 | 01 | 1 | INITIALIZE |
| 015 | 42 | STO | COUNTER |
| 016 | 14 | 14 | |
| 017 | 73 | RC* | FIND |
| 018 | 14 | 14 | INTERVAL |
| 019 | 22 | INV | |
| 020 | 77 | GE | |
| 021 | 00 | 00 | |
| 022 | 29 | 29 | |
| 023 | 01 | 1 | |
| 024 | 44 | SUM | |
| 025 | 14 | 14 | |
| 026 | 61 | GTO | |
| 027 | 00 | 00 | |
| 028 | 17 | 17 | |
| 029 | 43 | RCL | CALCULATE |
| 030 | 14 | 14 | LOCATION |
| 031 | 65 | × | OF |
| 032 | 05 | 5 | COEFFICIENTS |
| 033 | 85 | + | |
| 034 | 01 | 1 | |
| 035 | 00 | 0 | |
| 036 | 95 | = | |
| 037 | 42 | STO | |
| 038 | 82 | 82 | |
| 039 | 73 | RC* | RECALL |
| 040 | 82 | 82 | $a_0$ |
| 041 | 42 | STO | |
| 042 | 83 | 83 | |
| 043 | 01 | 1 | |
| 044 | 44 | SUM | |
| 045 | 82 | 82 | |
| 046 | 73 | RC* | RECALL |
| 047 | 82 | 82 | $a_1$ |
| 048 | 65 | × | |
| 049 | 43 | RCL | |
| 050 | 00 | 00 | |
| 051 | 95 | = | $a_1 V^1$ |
| 052 | 44 | SUM | |
| 053 | 83 | 83 | |
| 054 | 01 | 1 | |
| 055 | 44 | SUM | |
| 056 | 82 | 82 | |
| 057 | 73 | RC* | RECALL |
| 058 | 82 | 82 | $a_2$ |
| 059 | 65 | × | |
| 060 | 43 | RCL | |
| 061 | 00 | 00 | |
| 062 | 33 | X² | |
| 063 | 95 | = | $a_2 V^2$ |
| 064 | 44 | SUM | |
| 065 | 83 | 83 | |
| 066 | 01 | 1 | |
| 067 | 44 | SUM | |
| 068 | 82 | 82 | |
| 069 | 73 | RC* | RECALL |
| 070 | 82 | 82 | $a_3$ |
| 071 | 65 | × | |
| 072 | 43 | RCL | |
| 073 | 00 | 00 | |
| 074 | 45 | Y^X | |
| 075 | 03 | 3 | |
| 076 | 95 | = | $a_3 V^3$ |
| 077 | 44 | SUM | |
| 078 | 83 | 83 | |
| 079 | 01 | 1 | |
| 080 | 44 | SUM | |
| 081 | 82 | 82 | |
| 082 | 73 | RC* | RECALL |
| 083 | 82 | 82 | $a_4$ |
| 084 | 65 | × | |
| 085 | 43 | RCL | |
| 086 | 00 | 00 | |
| 087 | 45 | Y^X | |
| 088 | 04 | 4 | |
| 089 | 95 | = | $a_4 V^4$ |
| 090 | 44 | SUM | |
| 091 | 83 | 83 | |
| 092 | 29 | CP | CLEAR T |
| 093 | 43 | RCL | |
| 094 | 83 | 83 | |
| 095 | 58 | FIX | ROUND OFF |
| 096 | 03 | 03 | |
| 097 | 52 | EE | |
| 098 | 22 | INV | |
| 099 | 52 | EE | |
| 100 | 42 | STO | |
| 101 | 84 | 84 | |
| 102 | 22 | INV | |
| 103 | 58 | FIX | |
| 104 | 43 | RCL | INTERPOLATED |
| 105 | 84 | 84 | TEMPERATURE |
| 106 | 91 | R/S | |

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| 0 | | | |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |
| 12 | | | |
| 13 | | | |
| 14 | | | |
| 15 | | | |
| 16 | | | |
| 17 | | | |
| 18 | | | |
| 19 | | | |
| 20 | | | |
| 21 | | | |
| 22 | | | |
| 23 | | | |
| 24 | | | |
| 25 | | | |
| 26 | | | |
| 27 | | | |
| 28 | | | |
| 29 | | | |
| 30 | | | |
| 31 | | | |
| 32 | | | |
| 33 | | | |
| 34 | | | |
| 35 | | | |
| 36 | | | |
| 37 | | | |
| 38 | | | |
| 39 | | | |
| 40 | | | |
| 41 | | | |
| 42 | | | |
| 43 | | | |
| 44 | | | |
| 45 | | | |
| 46 | | | |
| 47 | | | |
| 48 | | | |
| 49 | | | |
| 50 | | | |
| 51 | | | |
| 52 | | | |
| 53 | | | |
| 54 | | | |

MERGED CODES

62 [Pgm] [Ind] 72 [STO] [Ind] 83 [GTO] [Ind]

63 [1/x] [Ind] 73 [RCL] [Ind] 84 [Σ+] [Ind]

64 [Prd] [Int] 74 [SUM] [Ind] 92 [INV] [SBR]

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COMMENTS ON PROGRAM I

| STEPS | |
|---|---|
| 00 to 13 | Pressing Label A starts program, stores voltage, $V_1$ for which temperature is to be calculated into Memory Location 00 and makes comparison to insure V is within correct range (in this case $2.3822 \geq V \geq .38345$). |
| 14 to 28 | Locates correct voltage range by comparing V to high value of voltage in each of 12 ranges. (These values are stored in Memory Locations 01 to 13). Locator Register (Memory Location 14) is initially set equal to 1. |
| 29 - 38 | Calculates the starting Memory Location of the coefficients of the polynomial selected. Stores starting location in Memory Location 82. |
| 39 - 91 | Evaluates the 4th order polynomial equation. The value corresponding to the location of the first polynomial coefficient, $a_0$, is in Memory Location 82. The next coefficient, $a_1$, is found by incrementing Memory Location 82 by 1. As the values of the terms of the polynomial are calculated, they are summed into Memory Location 83: When finished evaluating Memory Location 83 holds the answer. |
| 92 to 106 | Rounds the value in Memory Location 83 to 3 decimal places, stores the rounded value in Memory Location 84, clears the fixing condition back to full size and displays the rounded value from Memory Location 84. |

Table II - Memory Locations for Program I after an Interpolation calculation for 2.0153 volts.

| MEMORY LOCATION | VALUE | MEMORY LOCATION | VALUE |
|---|---|---|---|
| 00 | 2.0153 | 45 | 2074.966811 |
| 01 | 2.3822 | 46 | -6208.586484 |
| 02 | 2.2021 | 47 | 7116.287458 |
| 03 | 2.0267 | 48 | -3654.244386 |
| 04 | 1.8835 | 49 | 707.3400023 |
| 05 | 1.6675 | 50 | 404993.1391 |
| 06 | 1.3913 | 51 | -1396680.632 |
| 07 | 1.1763 | 52 | 1806751.599 |
| 08 | 1.0989 | 53 | -1038958.009 |
| 09 | 1.0422 | 54 | 224076.8687 |
| 10 | 0.9683866 | 55 | 6091130.855 |
| 11 | 0.780677 | 56 | -2308606.087 |
| 12 | 0.53053 | 57 | 3282707.07 |
| 13 | 0.38344 | 58 | -2075035.347 |
| 14 | 4. | 59 | 491881.7346 |
| 15 | 0. | 60 | -48117.41103 |
| 16 | 0. | 61 | 1926689.00922 |
| 17 | 0. | 62 | -2879948.535599 |
| 18 | 0. | 63 | 1910992.962868 |
| 19 | 0. | 64 | -475931.4242255 |
| 20 | -1094.283324 | 65 | 254.7583636 |
| 21 | 2328.799774 | 66 | 5226.586928844 |
| 22 | -1765.698837 | 67 | -1641.674902044 |
| 23 | 579.7823944 | 68 | 1371.790555 |
| 24 | -70.25141099 | 69 | -438.8594425511 |
| 25 | 343659.500004 | 70 | 747.8762571 |
| 26 | -544654.50945 | 71 | -2133.334189 |
| 27 | 453568.4019955 | 72 | 3728.4077933 |
| 28 | -141992.159918 | 73 | -3440.120102 |
| 29 | 1564.598503 | 74 | 1176.6330273 |
| 30 | -3424.102779 | 75 | 590.4916319 |
| 31 | -150454.1826 | 76 | -1878.955705 |
| 32 | -115633.47044 | 77 | 5571.0792025 |
| 33 | -39493.425567 | 78 | -8891.861835 |
| 34 | 5056.7451188 | 79 | 5188.952833 |
| 35 | -11225.811777 | 80 | 0. |
| 36 | 2562.0567227 | 81 | 0. |
| 37 | -218.0481 | 82 | 0. |
| 38 | 8.9196764 | 83 | 9.7575883 |
| 39 | -1.614922727 | 84 | 9.75 |
| 40 | 0.3797997 | 85 | 0. |
| 41 | -0.2302288 | 86 | 0. |
| 42 | 0.0944353 | 87 | 0. |
| 43 | -0.0255887 | 88 | 0. |
| 44 | 397.9060207 | 89 | 0. |



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Program II

TITLE Silicon Diode Thermometer Interpolation PAGE 1 OF 3

PROGRAMMER Ellen Fyffe DATE 10-6-78

TI Programmable **Program Record**

Partitioning (Op 17) [2,3,9,8,9] Library Module _____ Printer _____ Cards _____

## PROGRAM DESCRIPTION

This silicon diode temperature sensor interpolation program is designed to calculate the temperature (in degrees Kelvin) corresponding to a given voltage. The calculator performs a search routine to find the correct coefficients, then calculates T using the predetermined coefficients of a least square polynomial fit.

$$T = a_4 V^4 + a_3 V^3 + a_2 V^2 + a_1 V + a_0$$

NOTE: Not valid for voltages greater than 2.33785 volts, (1.9K). Range of validity 1.9° - 300°K.

## USER INSTRUCTIONS

| STEP | PROCEDURE | ENTER | PRESS | | | DISPLAY |
|---|---|---|---|---|---|---|
| 1 | Partitioning | 9 | 2nd | OP | 17 | 239.89 |
| 2 | Enter voltage (V) | V | | | | V |
| 3 | Calculate temperature (T) | | A | | | T |

| USER DEFINED KEYS | DATA REGISTERS ( STO RCL ) | | LABELS (Op 08) |
|---|---|---|---|
| A | 0 | 0 | |
| B | 1 | 1 | |
| C | 2 | 2 | |
| D | 3 | 3 | |
| E | 4 | 4 | |
| A' | 5 | 5 | |
| B' | 6 | 6 | |
| C' | 7 | 7 | |
| D' | 8 | 8 | |
| E' | 9 | 9 | |

| FLAGS | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|

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TITLE Program II
Silicon Diode Thermometer
Interpolation

PAGE 2 OF 3

PROGRAMMER Ellen M. Fyffe

DATE 10-6-78

TI Programmable
**Coding Form**

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| 000 | 76 | LBL | |
| 001 | 11 | A | |
| 002 | 42 | STO | |
| 003 | 00 | 00 | |
| 004 | 32 | X:T | |
| 005 | 01 | 1 | |
| 006 | 42 | STO | |
| 007 | 14 | 14 | |
| 008 | 73 | RC* | |
| 009 | 14 | 14 | |
| 010 | 22 | INV | |
| 011 | 77 | GE | |
| 012 | 00 | 00 | |
| 013 | 20 | 20 | |
| 014 | 01 | 1 | |
| 015 | 44 | SUM | |
| 016 | 14 | 14 | |
| 017 | 61 | GTO | |
| 018 | 00 | 00 | |
| 019 | 08 | 08 | |
| 020 | 07 | 7 | |
| 021 | 32 | X:T | |
| 022 | 43 | RCL | |
| 023 | 14 | 14 | |
| 024 | 77 | GE | |
| 025 | 00 | 00 | |
| 026 | 30 | 30 | |
| 027 | 61 | GTO | |
| 028 | 00 | 00 | |
| 029 | 43 | 43 | |
| 030 | 43 | RCL | |
| 031 | 14 | 14 | |
| 032 | 65 | × | |
| 033 | 05 | 5 | |
| 034 | 85 | + | |
| 035 | 01 | 1 | |
| 036 | 02 | 2 | |
| 037 | 95 | = | |
| 038 | 42 | STO | |
| 039 | 82 | 82 | |
| 040 | 61 | GTO | |
| 041 | 00 | 00 | |
| 042 | 92 | 92 | |
| 043 | 05 | 5 | |
| 044 | 32 | X:T | |
| 045 | 43 | RCL | |
| 046 | 14 | 14 | |
| 047 | 77 | GE | |
| 048 | 00 | 00 | |
| 049 | 53 | 53 | |
| 050 | 61 | GTO | |
| 051 | 00 | 00 | |
| 052 | 74 | 74 | |
| 053 | 43 | RCL | |
| 054 | 14 | 14 | |
| 055 | 65 | × | |
| 056 | 05 | 5 | |
| 057 | 85 | + | |
| 058 | 01 | 1 | |
| 059 | 01 | 1 | |
| 060 | 95 | = | |
| 061 | 42 | STO | |
| 062 | 82 | 82 | |
| 063 | 29 | CP | |
| 064 | 06 | 6 | |
| 065 | 32 | X:T | |
| 066 | 43 | RCL | |
| 067 | 14 | 14 | |
| 068 | 67 | EQ | |
| 069 | 01 | 01 | |
| 070 | 49 | 49 | |
| 071 | 61 | GTO | |
| 072 | 00 | 00 | |
| 073 | 92 | 92 | |
| 074 | 43 | RCL | |
| 075 | 14 | 14 | |
| 076 | 65 | × | |
| 077 | 05 | 5 | |
| 078 | 85 | + | |
| 079 | 01 | 1 | |
| 080 | 00 | 0 | |
| 081 | 95 | = | |
| 082 | 42 | STO | |
| 083 | 82 | 82 | |
| 084 | 29 | CP | |
| 085 | 04 | 4 | |
| 086 | 32 | X:T | |
| 087 | 43 | RCL | |
| 088 | 14 | 14 | |
| 089 | 67 | EQ | |
| 090 | 01 | 01 | |
| 091 | 49 | 49 | |
| 092 | 73 | RC* | |
| 093 | 82 | 82 | |
| 094 | 42 | STO | |
| 095 | 83 | 83 | |
| 096 | 01 | 1 | |
| 097 | 44 | SUM | |
| 098 | 82 | 82 | |
| 099 | 73 | RC* | |
| 100 | 82 | 82 | |
| 101 | 65 | × | |
| 102 | 43 | RCL | |
| 103 | 00 | 00 | |
| 104 | 95 | = | |
| 105 | 44 | SUM | |
| 106 | 83 | 83 | |
| 107 | 01 | 1 | |
| 108 | 44 | SUM | |
| 109 | 82 | 82 | |
| 110 | 73 | RC* | |
| 111 | 82 | 82 | |
| 112 | 65 | × | |
| 113 | 43 | RCL | |
| 114 | 00 | 00 | |
| 115 | 33 | $X^2$ | |
| 116 | 95 | = | |
| 117 | 44 | SUM | |
| 118 | 83 | 83 | |
| 119 | 01 | 1 | |
| 120 | 44 | SUM | |
| 121 | 82 | 82 | |
| 122 | 73 | RC* | |
| 123 | 82 | 82 | |
| 124 | 65 | × | |
| 125 | 43 | RCL | |
| 126 | 00 | 00 | |
| 127 | 45 | YX | |
| 128 | 03 | 3 | |
| 129 | 95 | = | |
| 130 | 44 | SUM | |
| 131 | 83 | 83 | |
| 132 | 01 | 1 | |
| 133 | 44 | SUM | |
| 134 | 82 | 82 | |
| 135 | 73 | RC* | |
| 136 | 82 | 82 | |
| 137 | 65 | × | |
| 138 | 43 | RCL | |
| 139 | 00 | 00 | |
| 140 | 45 | YX | |
| 141 | 04 | 4 | |
| 142 | 95 | = | |
| 143 | 44 | SUM | |
| 144 | 83 | 83 | |
| 145 | 29 | CP | |
| 146 | 43 | RCL | |
| 147 | 83 | 83 | |
| 148 | 91 | R/S | |
| 149 | 73 | RC* | |
| 150 | 82 | 82 | |
| 151 | 42 | STO | |
| 152 | 83 | 83 | |
| 153 | 01 | 1 | |
| 154 | 44 | SUM | |
| 155 | 82 | 82 | |
| 156 | 73 | RC* | |
| 157 | 82 | 82 | |
| 158 | 65 | × | |
| 159 | 43 | RCL | |

THIS PROG IS ... FROM CODE ...

MERGED CODES

| | | |
|---|---|---|
| 62 [Pgm] [A] | 72 [STO] [A] | 83 [GTO] [A] |
| 63 [B] [B] | 73 [RCL] [B] | 84 [C] [C] |
| 64 [D] [D] | 74 [SUM] [E] | 92 [INV] [SBR] |

TEXAS INSTRUMENTS
INCORPORATED

TITLE Program II
Silicon Diode Thermometer
Interpolation

PAGE 3 OF 3

PROGRAMMER Ellen M. Fyffe

DATE 10-6-78

TI Programmable
**Coding Form**

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| 160 | 00 | 00 | |
| 161 | 95 | = | |
| 162 | 44 | SUM | |
| 163 | 83 | 83 | |
| 164 | 01 | 1 | |
| 165 | 44 | SUM | |
| 166 | 82 | 82 | |
| 167 | 73 | RC* | |
| 168 | 82 | 82 | |
| 169 | 65 | × | |
| 170 | 43 | RCL | |
| 171 | 00 | 00 | |
| 172 | 33 | X² | |
| 173 | 95 | = | |
| 174 | 44 | SUM | |
| 175 | 83 | 83 | |
| 176 | 01 | 1 | |
| 177 | 44 | SUM | |
| 178 | 82 | 82 | |
| 179 | 73 | RC* | |
| 180 | 82 | 82 | |
| 181 | 65 | × | |
| 182 | 43 | RCL | |
| 183 | 00 | 00 | |
| 184 | 45 | Y× | |
| 185 | 03 | 3 | |
| 186 | 95 | = | |
| 187 | 44 | SUM | |
| 188 | 83 | 83 | |
| 189 | 01 | 1 | |
| 190 | 44 | SUM | |
| 191 | 82 | 82 | |
| 192 | 73 | RC* | |
| 193 | 82 | 82 | |
| 194 | 65 | × | |
| 195 | 43 | RCL | |
| 196 | 00 | 00 | |
| 197 | 45 | Y× | |
| 198 | 04 | 4 | |
| 199 | 95 | = | |
| 200 | 44 | SUM | |
| 201 | 83 | 83 | |
| 202 | 01 | 1 | |
| 203 | 44 | SUM | |
| 204 | 82 | 82 | |
| 205 | 73 | RC* | |
| 206 | 82 | 82 | |
| 207 | 65 | × | |
| 208 | 43 | RCL | |
| 209 | 00 | 00 | |
| 210 | 45 | Y× | |
| 211 | 05 | 5 | |
| 212 | 95 | = | |
| 213 | 44 | SUM | |
| 214 | 83 | 83 | |
| 215 | 29 | CP | |
| 216 | 43 | RCL | |
| 217 | 83 | 83 | |
| 218 | 91 | R/S | |
| 219 | 00 | 0 | |

MERGED CODES

| | | | | | |
|---|---|---|---|---|---|
| 62 | | 72 STO | | 83 STO | |
| 63 | | 73 RCL | | 84 | |
| 64 | | 74 SUM | | 92 INV | |

TEXAS INSTRUMENTS
INCORPORATED

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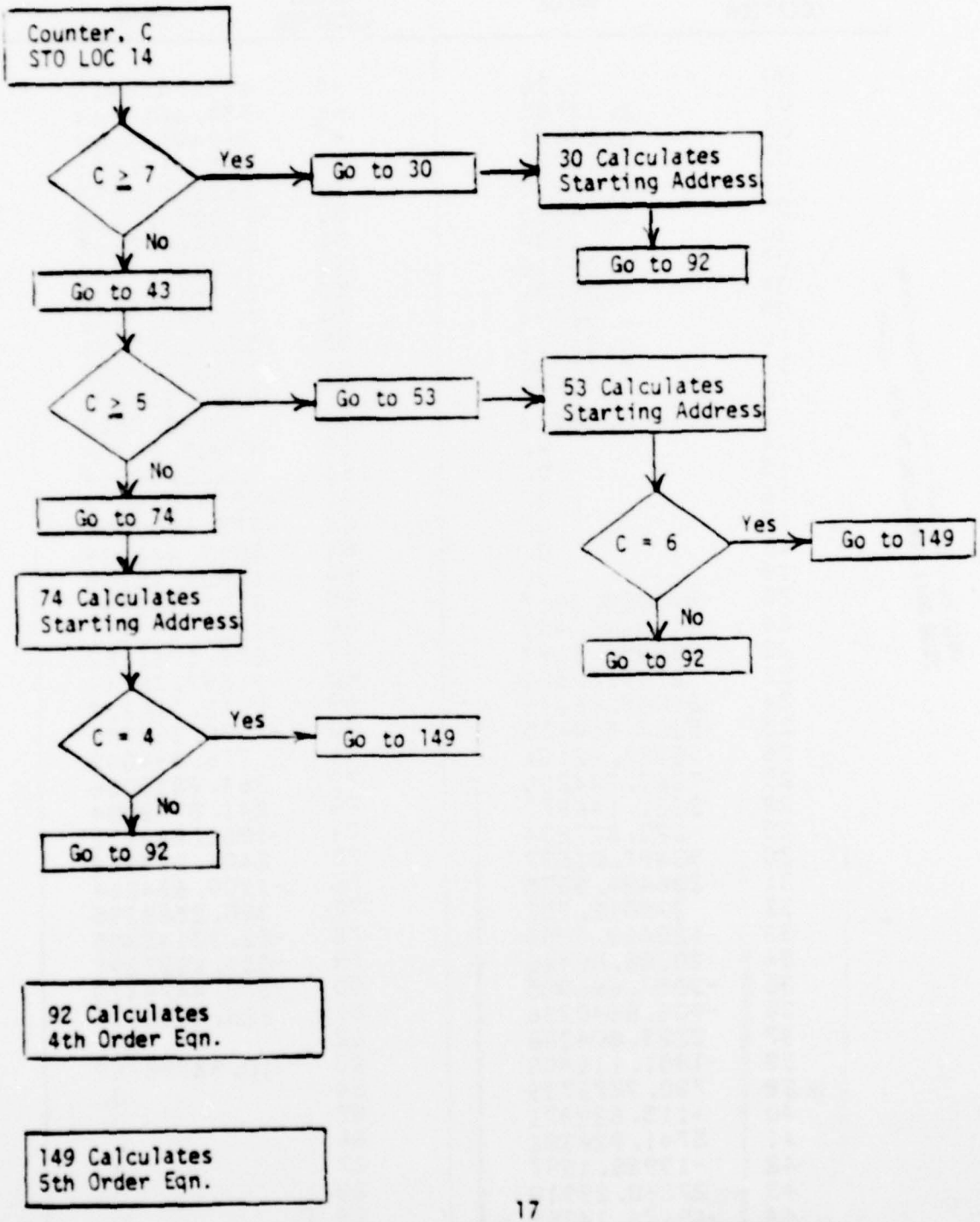
## COMMENTS

| PROGRAM STEPS | |
|---|---|
| 00 - 19 | Search routine for finding correct voltage-coefficient group. |
| 20 - 42 | Determining memory location for $a_0$ coefficient if counter $\geq 7$ (counter = storage 14). |
| 43 - 62 | Determining memory location for $a_0$ coefficient if counter $\geq 5$ but $<7$. |
| 63 - 73 | If counter = 6, go to 149 to determine T because need 5th-order polynomial |
| 74 - 83 | Determining memory location for $a_0$ coefficient if counter $<5$. |
| 84 - 91 | If counter = 4, go to 149 to determine T because need 5th-order polynomial. |
| 92 - 148 | Calculating T using 4th-order polynomial; storage 82 contains location of first ($a_0$) coefficient; must increment 82 to get coefficients of $v^1$, $v^2$, $v^3$, $v^4$, everything summed into storage 83. |
| 149 - 218 | Calculating T using 5th-order polynomial storage 82 contains location of first ($a_0$) coefficient, must increment 82 to get coefficients of $v^1$, $v^2$, $v^3$, $v^4$, $v^5$, everything summed into storage 83. |

In steps 63, 84, 145, 215, "2nd CP" is used to clear the T-register.

The memory locations are organized essentially the same as in Program I.

Figure 1. Flow Chart for Program II



## Memory Locations for Program II

| MEMORY LOCATION | VALUE | MEMORY LOCATION | VALUE |
|---|---|---|---|
| 00 | 1.96 | 45 | 6817.470413 |
| 01 | 2.33795 | 46 | -354.4819164 |
| 02 | 2.29616 | 47 | 363495.9699 |
| 03 | 2.10788 | 48 | -1253411.081 |
| 04 | 1.87985 | 49 | 1621291.977 |
| 05 | 1.56563 | 50 | -932274.3518 |
| 06 | 1.1834 | 51 | 201066.7865 |
| 07 | 1.09916 | 52 | 123069.3687 |
| 08 | 1.05251 | 53 | -507532.1238 |
| 09 | 0.98394 | 54 | 780390.7268 |
| 10 | 0.84011 | 55 | -530112.7351 |
| 11 | 0.67056 | 56 | 134249.7353 |
| 12 | 0.50025 | 57 | -6862.314076 |
| 13 | 0.36534 | 58 | 29835.75513 |
| 14 | 4. | 59 | -47005.16934 |
| 15 | 0. | 60 | 32622.66764 |
| 16 | 0. | 61 | -8519.715677 |
| 17 | 0. | 62 | 975.8603595 |
| 18 | 0. | 63 | 6013.442909 |
| 19 | 0. | 64 | -10829.45235 |
| 20 | -845428.3417 | 65 | 8191.263795 |
| 21 | 1468446.453 | 66 | -2328.162177 |
| 22 | -956496.6397 | 67 | 672.6761252 |
| 23 | 276915.608 | 68 | -1697.78714 |
| 24 | -30065.66472 | 69 | 2712.316235 |
| 25 | -5388.554485 | 70 | -2390.568791 |
| 26 | 10326.62134 | 71 | 776.494045 |
| 27 | -7360.744205 | 72 | 364.2819086 |
| 28 | 2321.146973 | 73 | 241.87420004 |
| 29 | -273.827634 | 74 | -1862.869172 |
| 30 | 93497.01597 | 75 | 2406.223958 |
| 31 | -236489.3375 | 76 | -1109.634264 |
| 32 | 239012.757 | 77 | 380.25682955 |
| 33 | -120613.0086 | 78 | -82.93142305 |
| 34 | 30386.86466 | 79 | -321.8337297 |
| 35 | -3057.666505 | 80 | -372.4476473 |
| 36 | -906.6640266 | 81 | 626.3486177 |
| 37 | 2223.804286 | 82 | 35. |
| 38 | -1981.118808 | 83 | 10.92755787 |
| 39 | 780.3879739 | 84 | 0. |
| 40 | -115.629971 | 85 | 0. |
| 41 | 5741.926382 | 86 | 0. |
| 42 | -19938.1997 | 87 | 0. |
| 43 | 27860.29918 | 88 | 0. |
| 44 | -19486.14265 | 89 | 0. |

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A method has been found to interpolate values from a large table of data quickly and accurately using a hand-held programmable calculator. Interpolation is accomplished by evaluation of polynomials which have previously been fit to the large data table. The method is perfectly general and in particular, is ideally suited to the interpolation of calibration tables in the laboratory while an experiment is in progress.

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